HÁSKÓLI ÍSLANDS
VERKFRÆÐI- OG NÁTTÚRUVÍSINDASVIÐ

# HYPERBOLIC AND SPHERICAL BLACK HOLES IN HYPERSCALING VIOLATING GEOMETRIES

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New!

Based on 1807.09770

with Juan Pedraza and Manus Visser

**Gauge/Gravity conference**
**31st of July, 2018, Würzburg**

# WHY HYPERSCALING VIOLATING GEOMETRIES

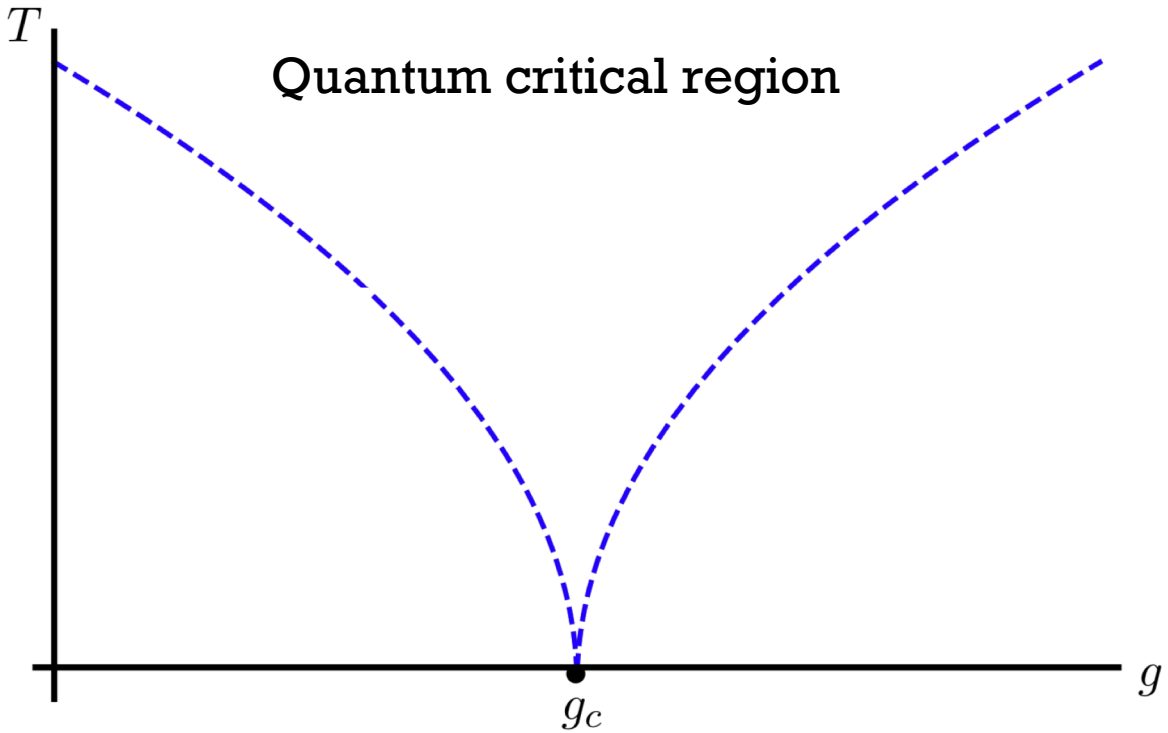
Holography and condensed matter:
"AdS/CMT"

Lifshitz geometries

$$\omega \sim |\vec{k}|^z$$

Hyperscaling violating (HSV) geometries

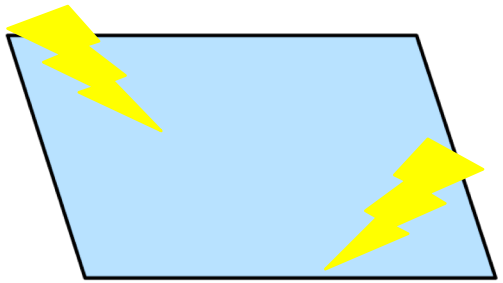
$$s \sim T^{(d-\theta)/z}$$




Quantum critical point

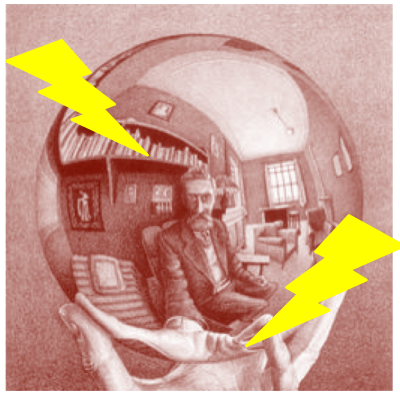
# OVERVIEW AND SOME SPOILERS

## Planar



- ✓ Anti-de Sitter
- ✓ Lifshitz
- ✓ HSV

## Spherical

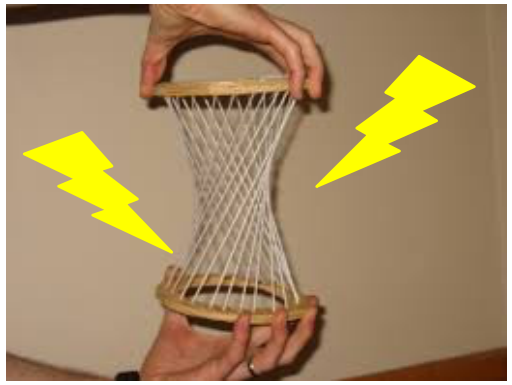


- ✓ Anti-de Sitter
- ✓ Lifshitz
- ✓ HSV

New!

phase transitions

## Hyperbolic



- ✓ Anti-de Sitter
- ✗ Lifshitz
- ✓ HSV

New!

$$\theta = d(z-1)$$

$$1 \leq z < 2$$

Absence tidal divergences

# ACTION SATISFYING EINSTEIN EQUATIONS

**Required scale Symmetry:** $r \to \lambda^{-1} r\,, \quad t \to \lambda^{z} t\,, \quad d\Omega_{k,d} \to \lambda d\Omega_{k,d} \qquad ds \to \lambda^{\theta/d} ds$

**HSV metric:** $$ds^2 = \left(\frac{r}{r_F}\right)^{-2\theta/d} \left[-\left(\frac{r}{\ell}\right)^{2z} f(r) dt^2 + \frac{\ell^2}{r^2 f(r)} dr^2 + r^2 d\Omega_{k,d}^2\right]$$

**HSV action:** $$S = -\frac{1}{16\pi G} \int d^{d+2}x \sqrt{-g} \left[R - \frac{1}{2}(\nabla\phi)^2 + V(\phi) - \frac{1}{4} X(\phi) F^2 - \frac{1}{4} Y(\phi) H^2 - \frac{1}{4} Z(\phi) K^2\right]$$

[Taylor'08]
[Tarrio, Vandoren'11]
[Alishahiha, Colgain, Yavartanoo'12]

**Blackening factor:** $$f = 1 + k\frac{(d-1)^2}{(d-\theta+z-2)^2}\frac{\ell^2}{r^2} - \frac{m}{r^{d-\theta+z}} + \frac{q^2}{r^{2(d-\theta+z-1)}}$$

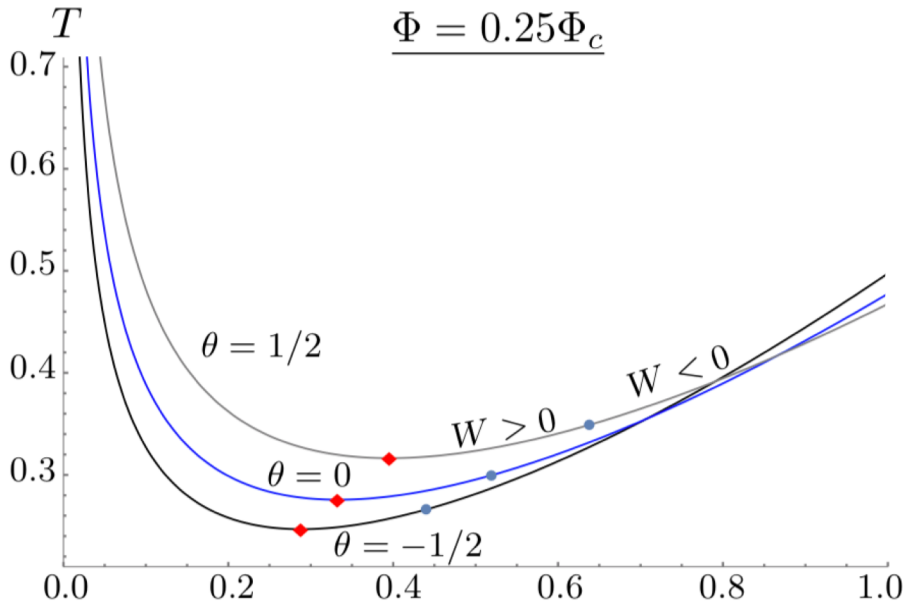
# NULL ENERGY CONDITION

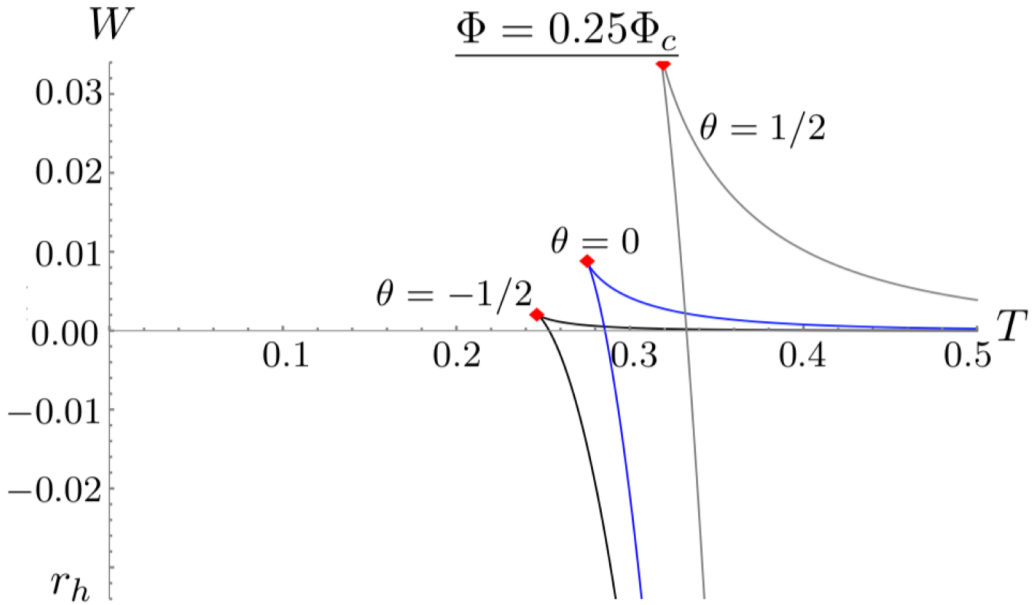
$$T_{\mu\nu}\xi^{\mu}\xi^{\nu} \geq 0$$

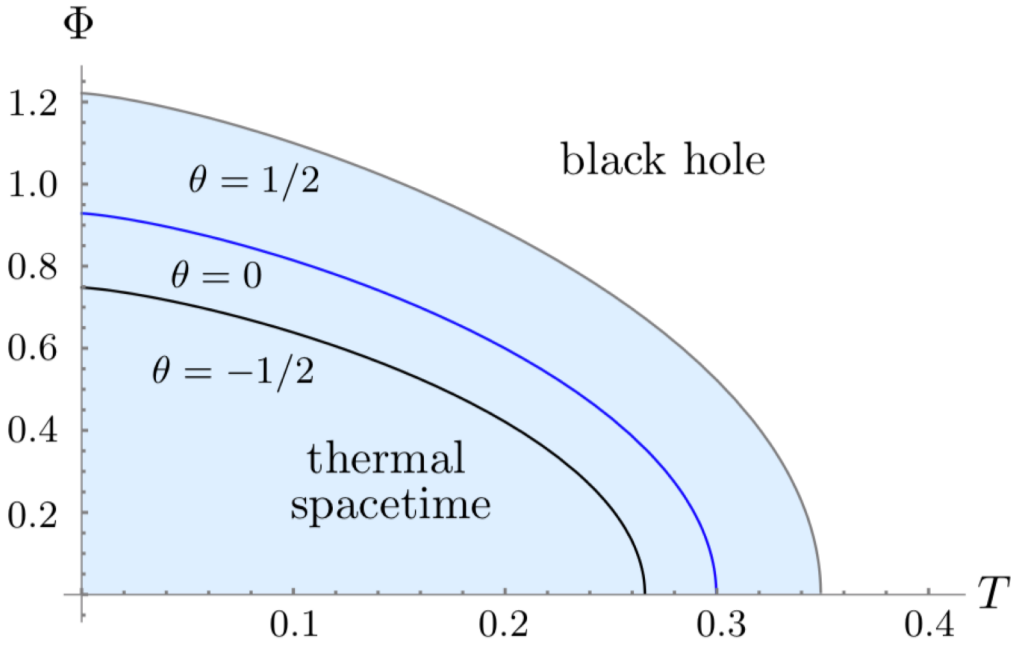
| $z$ | hyperbolic $k=-1$ | planar $k=0$ | spherical $k=1$ |
|---|---|---|---|
| $z<1$ | no solution | no solution | no solution |
| $1 \leq z < 2$ | $\theta = d(z-1)$ | $\theta \leq d(z-1)$ | $\theta \leq d(z-1)$ |
| $z \geq 2$ | no solution | $\theta < d$ | $\theta < d$ |

$d = 3$

$1 \leq z \leq 2$



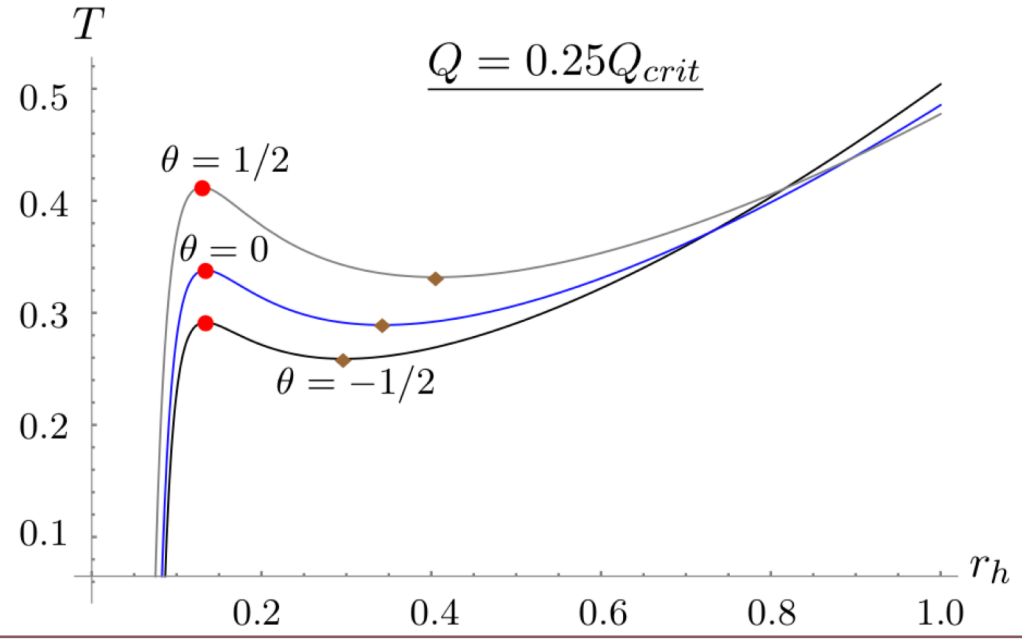



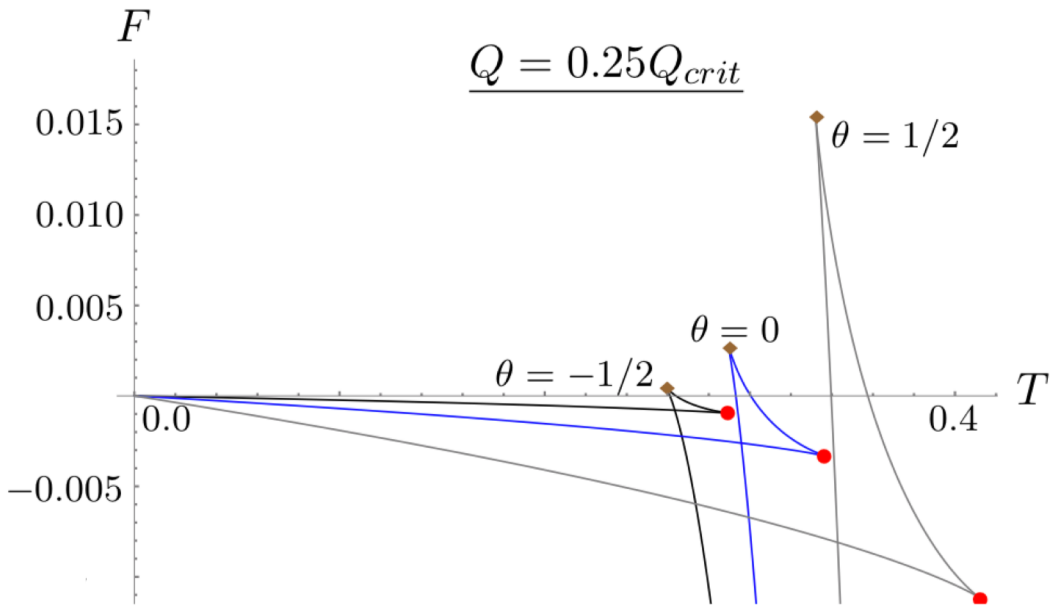



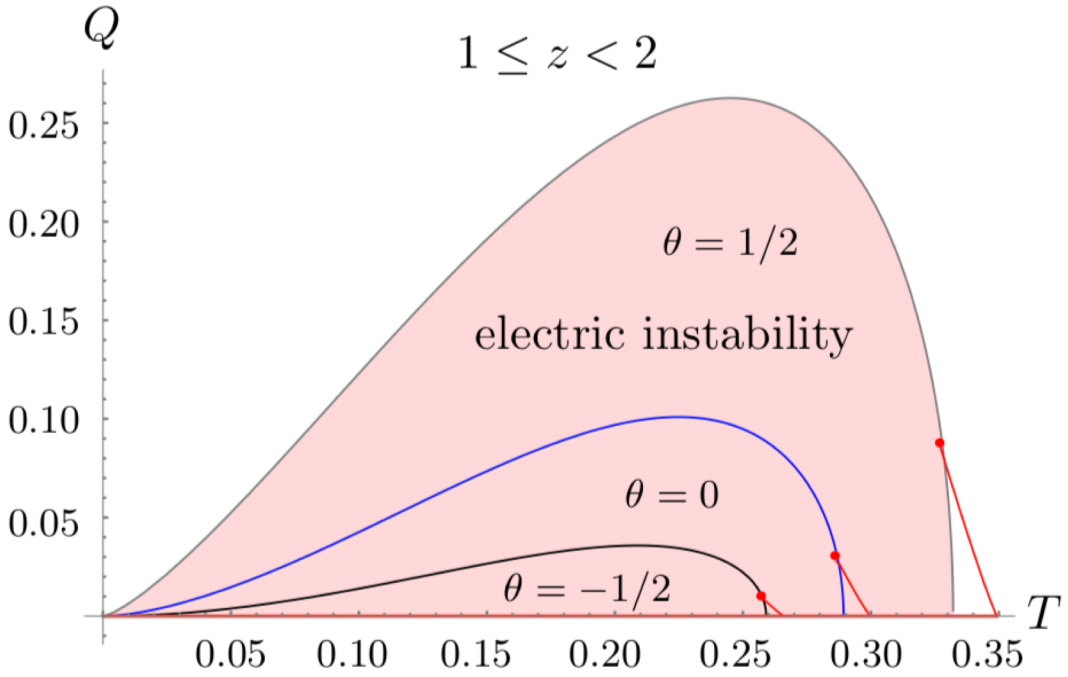

# GRAND CANONICAL ENSEMBLE

$d = 3$

$1 \leq z \leq 2$

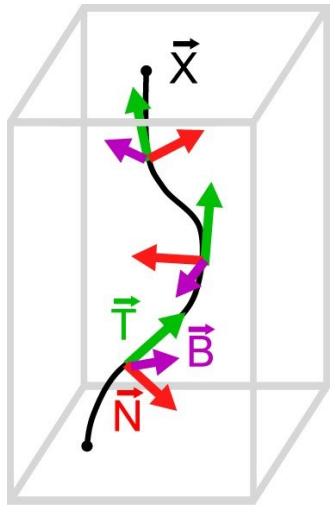



# CANONICAL ENSEMBLE

# ABSENCE TIDAL DIVERGENCE FOR ANY HORIZON




$$\theta = d(z-1)$$
$$1 \leq z < 2$$

Geodesically complete

[Shaghoulian'12]

# MASSLESS HYPERBOLIC BLACK HOLE

$$\theta = d(z-1)$$
$$1 \leq z < 2$$

Curvature invariants all finite!

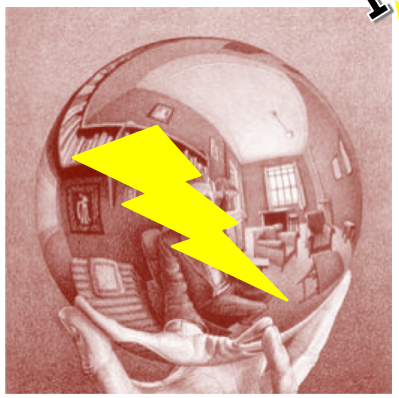
Non-zero temperature and entropy.

Special features massless: Rindler wedge?

[Emparan'99]
[Casini, Huerta, Myers'11]

# SUMMARY & OUTLOOK

New! ☑ HSV



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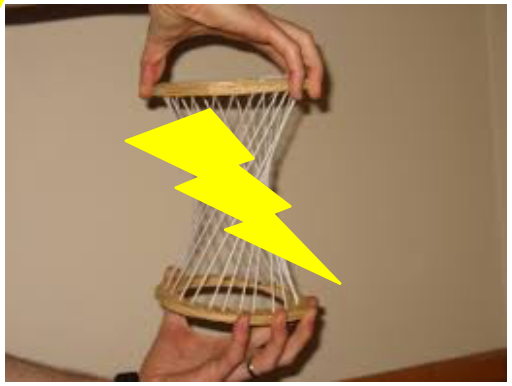

Absence tidal divergences

Massless hyperbolic black hole

Rindler wedge of …?

Extra symmetries?

Quasinormal modes

Hydrodynamics

Embedding

phase transitions

$$\theta = d(z-1)$$

$$1 \leq z < 2$$

Future

Thank you for listening !! Danke fürs Zuhören!!